(12) EUROPEAN PATENT APPLICATION

(21) Application number: 80105694.6

(22) Date of filing: 23.09.80

(51) Int. Cl.³: **H 01 F 27/24, H 01 F 1/16**

(54) Core for electromagnetic induction device.

(57) A magnetic core for an electromagnetic induction
device has a plurality of magnetic core elements (14). Each
of the core elements is formed by winding a plurality of
layers of uninsulated strip (18) of magnetically permeable
material. The core elements are juxtaposed together to
form a core stack, the height of which is large relative to
the strip width of each element. The core elements are
electrically isolated from each other by insulating material
(22) interposed between the elements at the region of
juxtaposition.
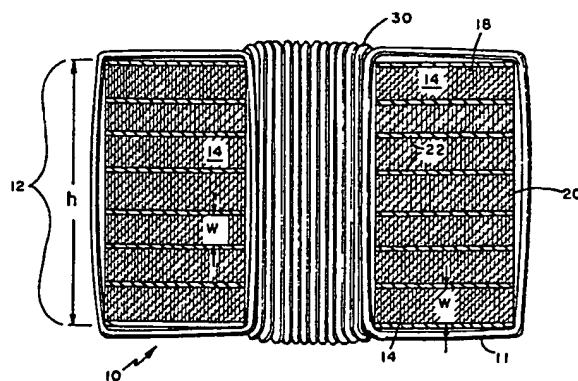
EP 0 026 871 A1

DESCRIPTION
CORE FOR ELECTROMAGNETIC INDUCTION DEVICE
BACKGROUND OF THE INVENTION
Field of the Invention

This invention relates to magnetic core
structures for use in electrical induction apparatus

5   such as transformers, motors, generators and the like.

Description of the Prior Art

Magnetic devices, such as transformers,
motors, generators and the like oftentimes include wound
core members composed of magnetically soft material.

10   The material, in the form of continuous strip is
typically wound on a suitable mandrel and annealed to
relieve winding stresses. The mandrel is then removed
from the core, which is cut and treated for receiving
windings thereon.

15   One of the major problems with toroidal core
members is the core loss produced by eddy currents
present in and between wound layers of the strip. This
loss, which varies as the square of strip width, is so
large that it has previously been necessary to form the

20   core from a number of laminated plates wound or stamped
from the strip, individually coated with insulating
material and wound or stacked one upon another on the
flat side thereof. As a result, magnetic cores for
electromagnetic induction devices have low operating

25   efficiency and high construction and material costs.

SUMMARY OF THE INVENTION

Briefly stated the present invention provides

a magnetic core for an electromagnetic induction device
that is economical to make and highly efficient in oper-
ation. The magnetic core comprises a plurality of mag-
netic core elements, each of which is formed by winding

5   a plurality of layers of uninsulated strip of magnet-
ically permeable material. The magnetic core elements
are juxtaposed together to form a core stack, the height
of which is large relative to the strip width of each
element. The core elements are electrically isolated

10   from each other by insulating material interposed
between the elements at the region of juxtaposition.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood
and further advantages will become apparent when

15   reference is made to the following detailed description
of the preferred embodiment of the invention and the
accompanying drawings, in which:

Figure 1 is a perspective view of a trans-
former incorporating the composite core of this inven-

20   tion;

Figure 2 is a section taken through line 2-2
of Fig. 1; and

Figure 3 is an exploded perspective view
illustrating the composite core construction of the

25   transformer shown in Fig. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figures 1 and 2 of the drawings,
there is shown generally at 10 an electromagnetic in-
duction device having the magnetic core 12 of this in-

30   vention. The magnetic core 12 comprises a plurality of
magnetic core elements 14. Each of the core elements
14 is formed by winding a plurality of layers 16 of
uninsulated strip 18 of magnetically permeable material.
The elements 14 are juxtaposed together to form a core

35   stack 20, the height, h, of which is large relative to
the strip width, w, of each element. Core elements 14
are electrically isolated from each other by insulating
material 22 interposed between the core elements 14 at

the region of juxtaposition 24.

The strip 18 used to wind the magnetic core
elements 14 is composed of magnetically soft material.
Such material desirably has the following combination of

5   properties: (a) low hysteresis loss; (b) low eddy
current loss; (c) low coercive force; (d) high magnetic
permeability; (e) high saturation value; and (f) minimum
change in permeability with temperature. Conventionally
employed magnetically soft material in strip form, such

10   as high-purity iron, silicon steels, iron/nickel alloys,
iron/cobalt alloys and the like, are all suitable for
use in the practice of the present invention. Particu-
larly suitable, however, is strip 18 of amorphous
(glassy) magnetic alloys which have recently become

15   available. Such alloys are at least about 50%
amorphous, as determined by x-ray diffraction. Such
alloys include those having the formula
$M_{60-90} T_{0-15} X_{10-25}$, wherein M is at least one of the
elements iron, cobalt and nickel, wherein T is at least

20   one of the transition metal elements, and X is at least
one of the metalloid elements of phosphorus, boron and
carbon. Up to 80 percent of the carbon, phosphorus
and/or boron in X may be replaced by aluminum, antimony,
beryllium, germanium, indium, silicon and tin. Used as

25   cores of magnetic devices, such amorphous metal alloys
evidence generally superior properties as compared to
the conventional polycrystalline metal alloys commonly
utilized. Preferably, strips of such amorphous alloys
are at least about 80% amorphous, more preferably yet,

30   at least about 95% amorphous.

The amorphous magnetic alloys of which strip
18 is preferably composed are formed by cooling a melt
at a rate of about 10^5 to 10^6°C/sec. A variety of well-
known techniques are available for fabricating rapid-

35   quenched continuous strip. When used in magnetic cores
for electromagnetic induction devices, the strip 18
typically has the form of wire or ribbon. The strip 18
is conveniently prepared by casting molten material

directly onto a chill surface or into a quenching medium of some sort. Such processing techniques considerably reduce the cost of fabrication, since no intermediate wire-drawing or ribbon-forming procedures are required.

The amorphus metal alloys of which strip 18 is preferably composed evidence high tensile strength, typically about 200,000 to 600,000 psi (1.38-4.14 x 10^6 kPa), depending on the particular composition. This is to be compared with polycrystalline alloys, which are used in the annealed condition and which usually range from about 40,000 to 80,000 psi (2.76-5.52 x 10^6 kPa). A high tensile strength is an important consideration in applications where high centrifugal forces are present, such as experienced by cores in motors and generators, since higher strength alloys allow higher rotational speeds.

In addition, the amorphous metal alloys used to form strip 18 evidence a high electrical resistivity, ranging from about 160 to 180 microhm-cm at 25°C, depending on the particular composition. Typical prior art materials have resistivities of about 45 to 160 microhm-cm. The high resistivity possessed by the amorphous metal alloys defined above is useful in AC applications for minimizing eddy current losses, which, in turn, are a factor in reducing core loss.

A further advantage of using amorphous metal alloys to form strip 18 is that lower coercive forces are obtained than with prior art compositions of substantially the same metallic content, thereby permitting more iron, which is relatively inexpensive, to be utilized in the strip 18, as compared with a greater proportion of nickel, which is more expensive.

Referring to Figs. 2 and 3 of the drawings, each of the magnetic core elements 14 is formed by winding successive turns of strip 18 on a mandrel (not shown). During winding of successive turns, strip 18 is kept under tension to effect tight formation of the core element 14. The number of turns required for a given

core element 14 can range from a few turns to several
thousand turns, depending upon the power capacity of the
electromagnetic device desired. When the required
number of turns are wound for a given core element 14,
5   the strip 18 is cut across the width, w, thereof, the
outer turn being held in wound relation to the preceding
turn. Typically, the cut end of the last turn of strip
18 is spot welded, clamped or otherwise secured to the
wound core element 14.

10   When sufficient turns have been wound to form
a given magnetic core element 14 as above described, the
mandrel is removed therefrom to produce the core element
14 shown in Fig. 3. The core element 14 has a width
defined by the width of strip 18 and a build defined by
15   the number of turns of strip 18 times the strip thick-
ness, t. Amorphous metal strip is relatively thin as
compared to rolled crystalline strip. Moreover, the
composite core construction of magnetic core 12
eliminates the necessity for individually coating each
20   wound layer of strip 18 used to form core element 14.
As a result, the core element 14 can be wound into a
smaller, lighter element at lower construction, process-
ing and material costs than magnetic cores having an
insulated interlaminar construction. Generally, the
25   width of strip 18 ranges from about .25 to 2.5 centi-
meters and the thickness of strip 18 ranges from about 1
to 2 mils. The build of each core element 14 can range
from as low as 4 mils to as great as 25 centimeters or
more depending upon the power requirements of the
30   electromagnetic device.

         Magnetic core 12 is assembled by sandwiching
a layer of insulating material 22 between plural core
elements 14. The core elements 14 may be bonded
together by the insulating material 22. Alternatively,
35   core elements 14 and insulation layers 22 can be placed
successively on a spool composed of thermoplastic or
thermosetting material. The number of core elements 14
used to construct magnetic core 12, as well as the

dimensions of the core elements 14 and overall height, h, of the magnetic core 12 will vary depending on the power capacity and operating frequency of the electro-magnetic device. For electromagnetic devices having an

5 operating frequency of 60 Hz and a power capacity rang-ing from 100 to 20,000 watts, the maximum acceptable strip width is about 1 inch (2.54 cm) the number of core elements 14 used to construct magnetic core 12 is about 3 to 10, the height, h, of magnetic core 12 is about 2

10 to 10 inches (5.08-25.4 cm) the inside diameter of each core element 14 is about 1 to 6 inches (2.54-1.52 cm) and the outside diameter of each core element 14 is about 2 to 20 inches (5.08-50.8 cm). For electromagnetic devices having an operating frequency of

15 about 10 KHz and a power capacity ranging from 100 to 20,000 watts, the maximum acceptable strip width is about 1/4 inch (6.3×10^{-1} cm), the number of core elements 14 used to construct magnetic core 12 is about 3 to 10, the height, h, of magnetic core 12 is about 2

20 to 10 inches (5.08-25.4 cm), the inside diameter of each core element 14 is about 1 to 3 inches (2.54-7.62 cm) and the outside diameter of each core element 14 is about 2 to 10 inches (5.08-25.4 cm).

The insulating layers 22 disposed between core

25 elements 14 can be composed of any suitable insulating material such as thermosetting or thermoplastic material, glass cloth, fiberglass, polycarbonates, mica, CAPSTAN, LEXAN, fish paper and the like, having the required flexibility, dielectric strength, toughness

30 and stability at the design operating temperature of the magnetic core 12, normally in the vicinity of 130°C. As shown in Fig. 3, insulating layers 22 are in the form of a flexible film having a thickness of about 1/2 mil and inside and outside diameters substantially equivalent to

35 those of core elements 14. Electrical isolation of core elements 14 can alternatively be accomplished by dispos-ing insulating material over part of the build portions between adjoining core elements 14. Thus, the insulating

layer 22 disposed between adjoining core elements 14 can have the form of a spider or other suitable configuration adapted to physically separate and electrically isolate the adjacent core elements 14. In such a case,

5   electrical isolation of core elements 14 is effected by an insulating layer 22 comprised in part of air. Still further, the insulating layer 22 can be painted, sprayed or otherwise applied to one or both of the adjoining surfaces of core elements 14.

10   Construction of a transformer 11 incorporating magnetic core 12 can be readily effected by toroidal winding of primary and secondary turns 30, 32 of copper or aluminum wire or ribbon about the magnetic core 12, or by hand threading the copper or aluminum wire turns

15   about the magnetic core 12 in a conventional manner. The elimination of interlaminar insulation afforded by the sectionalized construction of magnetic core 12 substantially reduces the length of the copper turn required, and decreases the copper loss of the

20   electromagnetic device 10.

The reduction in core loss resulting from the composite core construction of magnetic core 12 has been demonstrated by a 15 KVA transformer wound with seven core elements 14 of 1 inch (2.54 cm) wide uncoated strip

25   18.

If the transformer core had been wound with uncoated strip 18 in the form of wide ribbon in a single section, a current, I, would have flowed between the ribbon layers. This current would be $\frac{E}{R}$ where E is the

25   voltage induced in the magnetic core and R the effective interlayer resistance. As per Faraday's Law of Induction, E is proportional to the frequency, the flux density and the core area. R, the effective inter- layer resistance, is proportional to the interlayer

35   resistivity and inversely proportional to the area of contact between the layers. The interlayer core loss would then be: $P = I^2 R = \frac{E^2}{R}$

If, on the other hand, the magnetic core 12 is sectioned

into "n" number of core elements 14 insulated from each other, in accordance with the invention, there will now be a current i flowing in each core element 14 due to an induced voltage e and an interlayer resistance r.

5 Since the core area of the core element 14 is now n times smaller, the induced voltage e is:

$$e = \frac{E}{n} \qquad (1)$$

The contact area determining the interlayer resistance is now n times smaller, therefore the effective inter-

10 layer resistance of each element is:

$$r = nR \qquad (2)$$

The interlayer core loss, p, of each element will be:

$$p = i^2 r = \frac{e^2}{r}$$

Substituting for e and i from equations 1 and 2:

$$p = \frac{E^2}{R\,n3}$$

15 Since the core is composed of n sections, the total interlayer core loss, P, will be:

$$P = np = \frac{E^2}{R\,n2}$$

Or, in other words, n2 times less than when the core is

20 wound as a single element. In the 15 KVA transformer consisting of seven elements, the interlayer core loss is 49 times lower than it would be if it had been wound as a single section with 7 inch (17.78 cm) wide uncoated strip.

25   Having thus described the invention in rather full detail it will be understood that these details need not be strictly adhered to but that various changes and modifications may suggest themselves to one skilled in the art, all falling within the scope of the inven-

30 tion as defined by the subjoined claims.

35

What is claimed is:

1. A magnetic core for an electromagnetic in-
duction device, comprising:

a. a plurality of magnetic core elements,
each of said core elements being formed by wind-
ing a plurality of layers of uninsulated strip
of magnetically permeable material;

b. said magnetic core elements being
juxtaposed together to form a core stack, the
height of which is large relative to the strip
width of each element; and

c. said magnetic core elements being
electrically isolated from each other by insulat-
ing material interposed between the elements at
the region of juxtaposition.

2. A magnetic core as recited in claim 1,
wherein said strip is composed of a metal alloy that is
at least 50 percent amorphous and has a composition
defined by the formula $M_{60-90} T_{0-15} X_{10-25}$
wherein M is at least one of the elements iron, cobalt
and nickel, T is at least one of the transition metal
elements and X is at least one of the metalloid elements
phosphorus, boron and carbon.

3. A magnetic core as recited in claim 2,
wherein up to 80 percent of component X is replaced by
at least one of aluminum, antimony, beryllium,
germanium, indium, silicon and tin.

4. A magnetic core as recited in claim 2,
wherein said strip is at least about 80 percent amor-
phous.

5. A magnetic core as recited in claim 2,
wherein said strip is at least about 95 percent amor-
phous.

6. A magnetic core as recited in claim 1,
wherein said core stack has a height ranging from about
2 to 10 inches (5.08-25.4 cm) and said strip width
ranges from about .25 to 2.5 centimeters.

7. A magnetic core as recited in claim 1,

wherein said plurality of core elements ranges from
2 to 10.

8. A magnetic core as recited in claim 1,
wherein each of said core elements has a build ranging
from about 4 mils to 25 centimeters.

9. An electromagnetic device having a
primary, a secondary and a magnetic core, said magnetic
core comprising:

a. a plurality of magnetic core elements,
each of said core elements being formed by wind-
ing a plurality of layers of uninsulated strip
of magnetically permeable material;

b. said magnetic core elements being jux-
taposed together to form a core stack, the height
of which is large relative to the strip width of
each element; and

c. said magnetic core elements being
electrically isolated from each other by insulat-
ing material interposed between the elements at
the region of juxtaposition.

10. An electromagnetic device as recited in
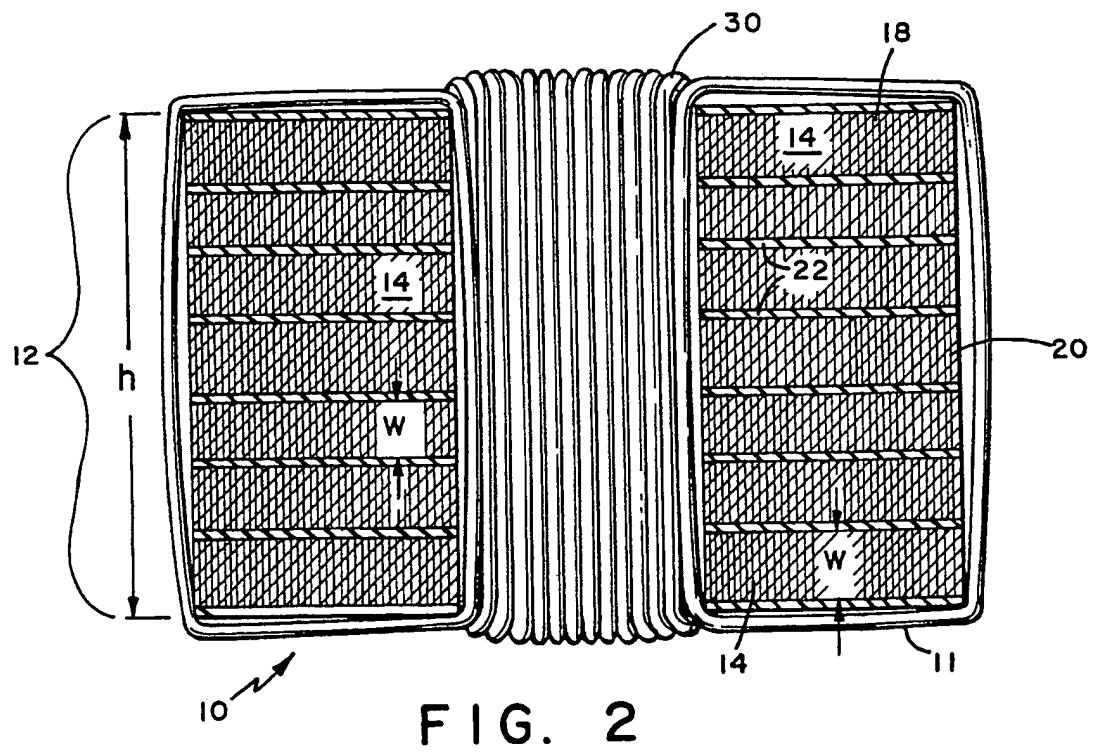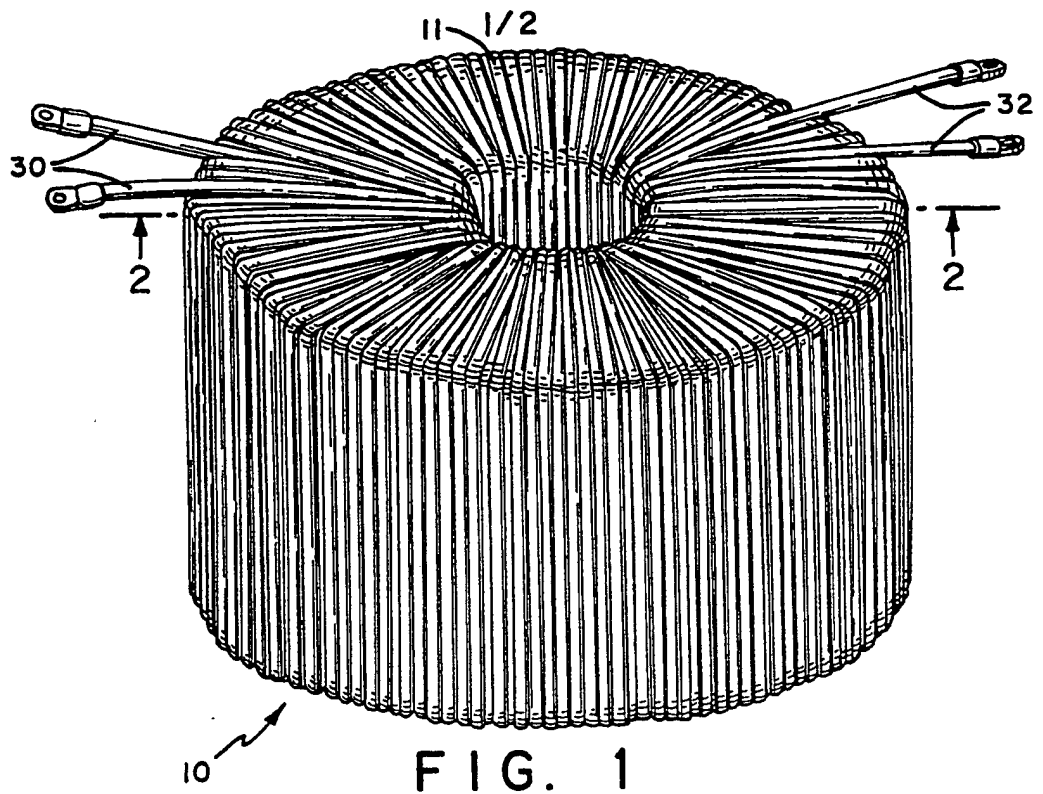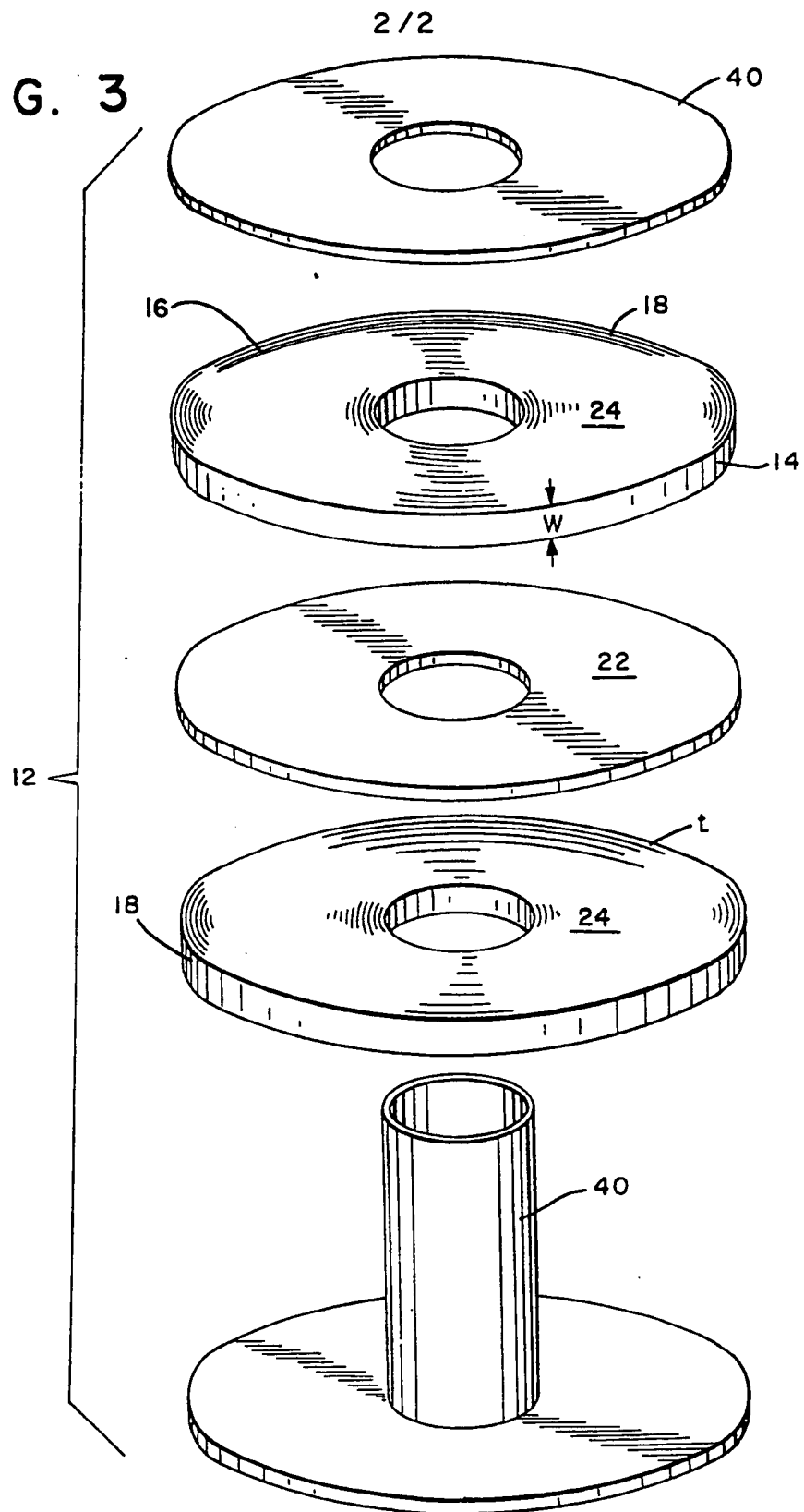claim 9, wherein said device is a transformer.

FIG. 1

FIG. 2

FIG. 3

European Patent
Office

EUROPEAN SEARCH REPORT

0026871

Application number

EP 80 10 5694

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.³)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	GB - A - 1 453 154 (ELPHIAC) * Page 1, lines 56-88 * --	1	H 01 F 27/24 1/16
	US - A - 2 909 742 (GENERAL ELEC-TRIC) * Column 1, lines 15-16 * --	1,9,10	
	US - A - 4 056 411 (HO SOU CHEN) * Column 2, lines 12-40; column 3, lines 44-50 * --	2,3	
A	DE - C - 937 185 (SIEMENS)		**TECHNICAL FIELDS SEARCHED (Int. Cl.³)** H 01 F 27/24 3/04 31/00 1/14 1/16
A	GB - A - 1 525 959 (HO-SOU CHEN)		
A	US.- A - 3 838 365 (ALLIED CHEMI-CAL CORP.)		
A	US - A - 4 038 073 (ALLIED CHEMI-CAL CORP.)		
A	US - A - 4 116 728 (GENERAL ELEC-TRIC) ----		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	17-12-1980	VANHULLE

EPO Form 1503.1 06.78